History of the LAPPD Collaboration July 2009- Dec. 2012

Henry Frisch
Enrico Fermi Institute, University of Chicago

Apologia-
As in all history written by a participant, this is only my account. I've done my best to go back to the original documents, but apologize in advance for errors, omissions and unintended slights.

The LAPPD Collaboration of 3 national labs, 3 universities, and 3 US companies was funded in July/Aug 2009 as detector R&D by the DOE thanks to Howard Nicholson and Glenn Crawford. The Collaboration ended after 3 ½ years, followed by the transition from R&D to technology transfer.

A proposal for R&D was submitted April 2009 – the next slide listing the Collaboration was shown at a DOE visit to ANL in early May 2009*.

*
Note: in hindsight, there is an error on the 2009 slide. Space Sciences Laboratory was counted as a National Laboratory; it is part of UC Berkeley, so the initial count should be 3 rather than 4 National Labs and 3 rather than 2 universities. We also worked with 6 ANL Divisions

Plans to Implement This

The Development of Large-Area Fast Photo-detectors

April 15, 2009

John Anderson, Karen Byrum, Gary Drake, Edward May, Alexander Paramonov, Mayly Sanchez, Robert Stanek, Hendrik Weerts, Matthew Wetstein[1], Zikri Yusof
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Argonne National Laboratory, Argonne, Illinois 60439

Bernhard Adams, Klaus Attenkofer
Advanced Photon Source Division
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Zeke Insepov
Mathematics and Computer Sciences Division
Argonne National Laboratory, Argonne, Illinois 60439

Jeffrey Elam, Joseph Libera
Energy Systems Division
Argonne National Laboratory, Argonne, Illinois 60439

Michael Pellin, Igor Veryovkin, Hau Wang, Alexander Zinovev
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Fermi National Accelerator Laboratory, Batavia, Illinois 60510

James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman, Gary Varner
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Oswald Siegmund, Anton Tremsin
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Dmitri Routkevitch
Synkera Technologies Inc., Longmont, CO 80501

David Forbush, Tianchi Zhao
Department of Physics, University of Washington, Seattle, WA 98195

[1] Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

Have formed a collaboration to do this in 3 years. 4 National Labs, 5 Divisions at Argonne, 3 companies, electronics expertise at UC and Hawaii

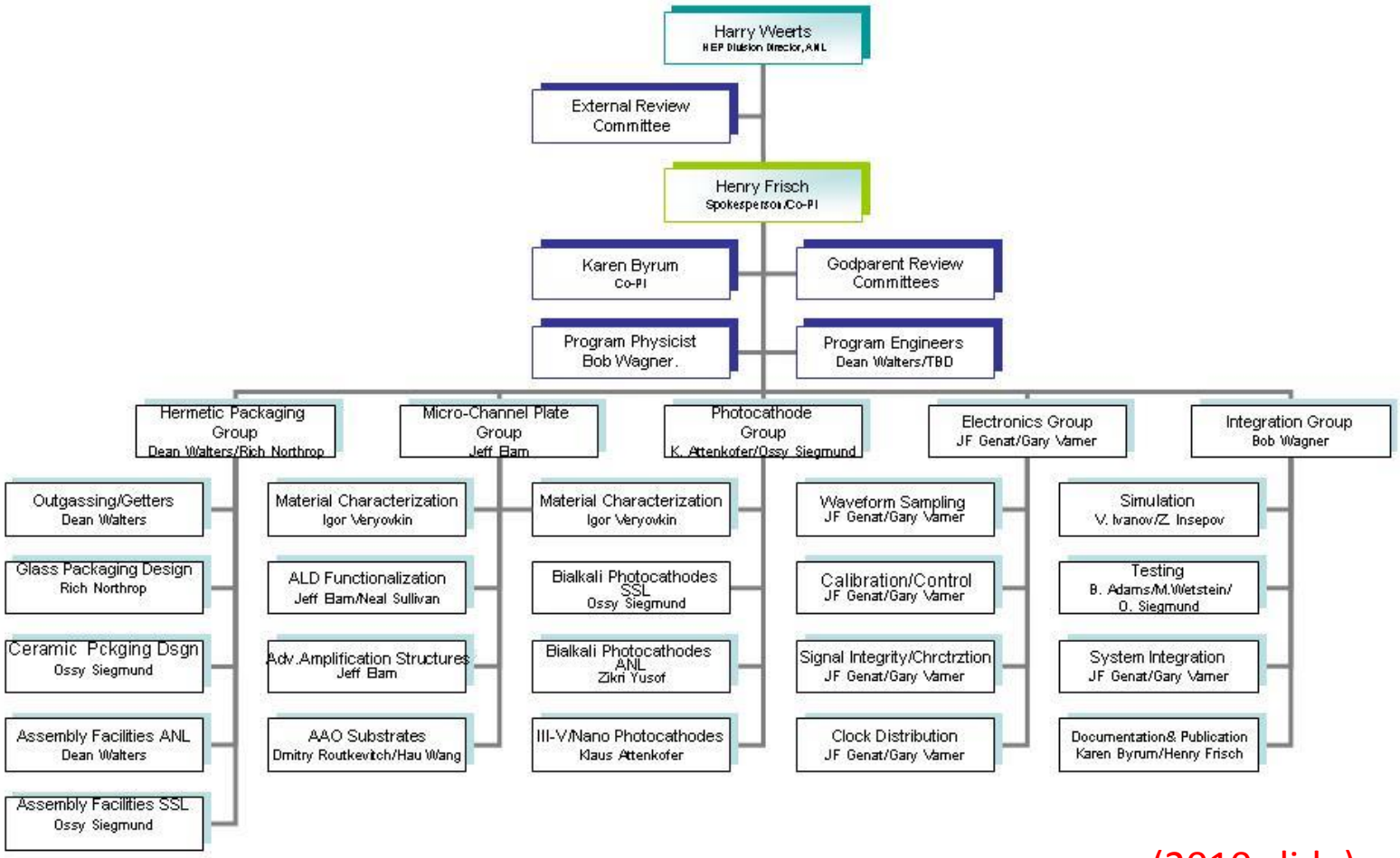
R&D- not for sure, but we see no show-stoppers

The Large-Area Psec Photo-Detector Collaboration-2010

Version 2.0
Feb. 9, 2010

Organization Chart

R&D Program for the Development of Large-Area Fast Photodetectors



(2010 slide)

Parallel Efforts on Specific Applications

Old Slide

Organization of the Collaboration

The primary institution was ANL; funding from the DOE Office of High Energy Physics was managed by the HEP Division (HEPD), with subcontracts to the universities and companies.

1. As **Spokesperson** I was offered a Joint Appointment with ANL/HEPD, with some R&D funds and a postdoc position (I hired Matt)- a natural alliance as UC manages ANL. I reported to Harry Weerts, the **Director of HEPD**.

2. Bob Wagner (ANL) was **Project Physicist**, and was our interface to the ANL financials management system.

3. We divided the R&D effort into 4 areas, each with 2 leaders (typ.) and its own `**Godparent Committe**e'- a review committee comprising both outside experts and critics, and internal collaborators from the 3 areas not being reviewed and that met twice a year (i.e. 8 reviews per year total). The GP's were charged with making a written-report; we requested that the area leaders write a written response to the report (these are on the psec web page).

4. We reviewed work and planned next steps by having two Collaboration Meetings per year (also on the psec web page- tho some ANL links are broken).

5. We (Klaus Attenkofer was invaluable) organized workshops (Chicago,France) on specific problems-assigned talks to experts, even if we didn't know them.

* (see web site).

Note: in internal discussions even before talking with the DOE we favored this model over individual DOE contracts to the universities for coherence of effort and better accounting.

R&D used complementary strengths of Natl. Labs, Universities, Industry

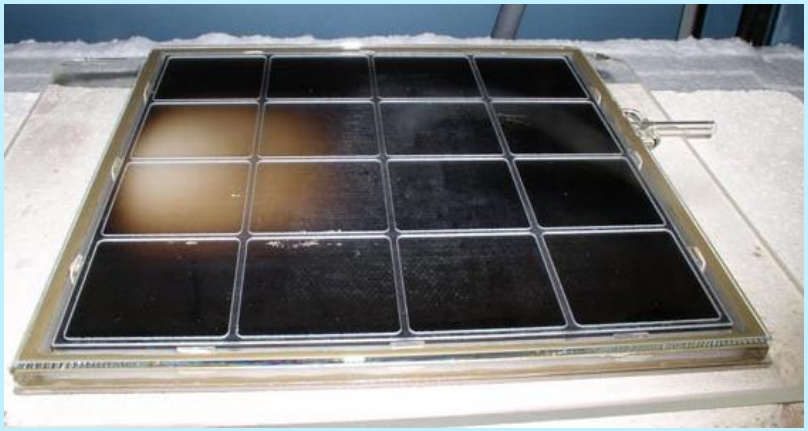
- Natl Labs have extraordinary facilities, expertise- ANL is especially strong in MSD (M. Pellin, I. Veryovkin), ESD (Jeff Elam), XSD (Klaus Attenkofer, Bernhard Adams, APS lab).
- Universities have world-class facilities and expertise in specific areas– SSL (Ossy), Hawaii (Gary).
- Industry has a complementary set of facilities and expertise, and also a discipline and methodology that neither the Labs nor the Universities have.

Three other factors were crucial for LAPPD:

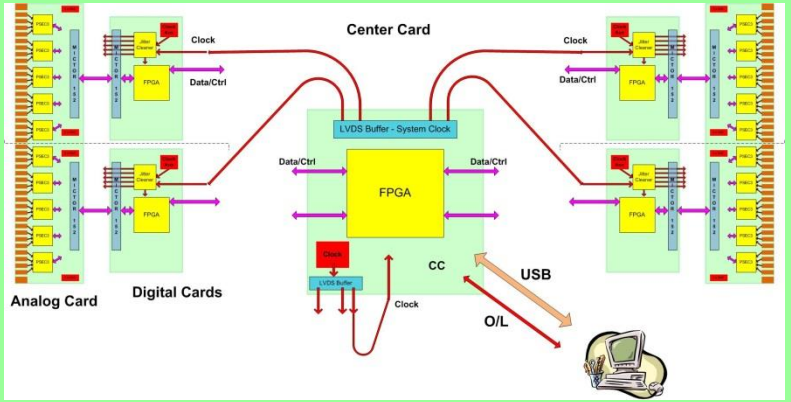
- All the senior management worked hands-on (no high salaries for only oversight of a small group)
- All the senior management had extensive technical experience (Ossy (SSL), Gary (UH), Michael (Incom)
- We had world-class expertise (I claimed the best in the world) in each area: Ossy, Gary, Jeff Elam, Michael)

The 4 `Divisions' of glass LAPPD

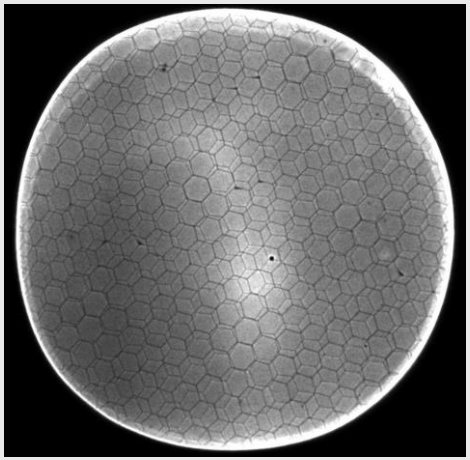
Hermetic Packaging



Electronics/Integration



MicroChannel Plates



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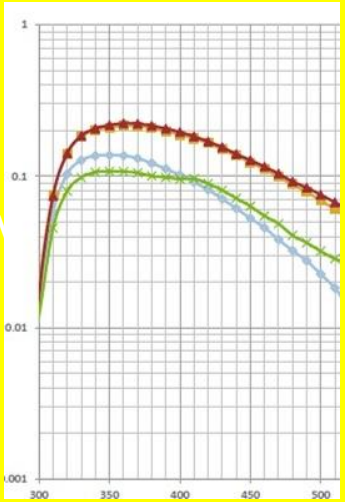
Photocathodes



2010 GodParent Review Panels

Packaging Group	MCP Group	Photocathode Group	Electronics Group
Karen Byrum	**Bob Wagner**	**Gary Varner**	**Zikri Yusof**
K. Arisaka	K. Attenkofer	J. Buckley	B. Adams
J. Elam	A. Bross	K. Harkay	M. Demarteau
D. Ferenc	Z. Insepov	V. Ivanov	G. Drake
J.F. Genat	A. Tremsin	A. Lyashenko	T. Liu
P. Hink	J. Va'vra	T. Prolier	I. Veryovkin
A. Ronzhin	A. Zinovev	M. Wetstein	S. Ross

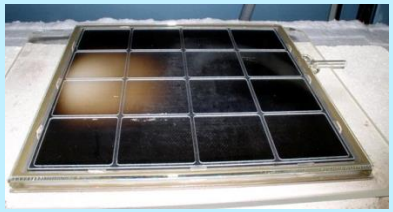
Note added: note that the Chair was internal to LAPPD but from a different area

‘Portfolio of Risk’- Parallel Efforts

- **Two parallel but intertwined efforts at different levels of risk, reward:**
  - **SSL/Hawaii** (Siegmund)- ceramic package based on Planacon experience, NaKSb cathode, higher cost, smaller area, lower throughput, **lower risk due to fewer innovations, more experience;**
  - **ANL/UC** (Wagner, Byrum,Frisch)- glass package, KCsSb cathode, lower cost, larger area, higher throughput, **higher risk, but more innovation and use of new technologies.**
- **Reduce risk and enhance reward by diversification onto the 2 paths.** Has proved very beneficial to both efforts (much cross-fertilization, and shared MCP development)

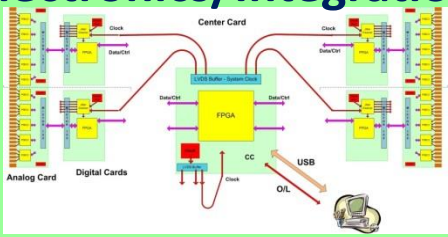
Achievements of DOE R&D

Hermetic Packaging



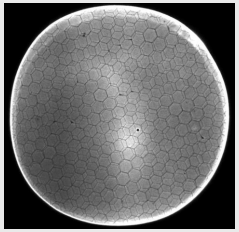
- `Frugal '(Tshirt) 1.6-GHz glass anode
- `Frugal' no-pin B33 glass package
- ALD-based internal voltage divider
- `Frugal' Frit glass bottom seal
- Large-area Multi-tile Supermodule

Electronics/Integration



- `
- 15 Gs/sec 6-channel `scope-in-a-chip'
- Full DAQ design – 2 layers of FPGA
- Test setups at Hawaii and Chicago
- Student leadership on ASICs,firmware

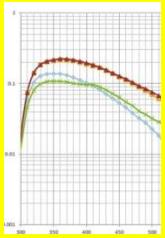
MicroChannel Plates



- High-quality 8" 20μ substrates (Incom)
- Proprietary ALD coatings with <0.1 cts/cm^2/s, gains> 10^7, `no' aging
- Multiple test stations at ANL, SSL

Photocathodes

CV



- 8" SbKNa cathode (SSL)
- Cathode facility/lab (ANL)
- SbKCs cathode with 24% QE (ANL)
- InGaN development (WashU)
- Started high-QE cathode collaboration

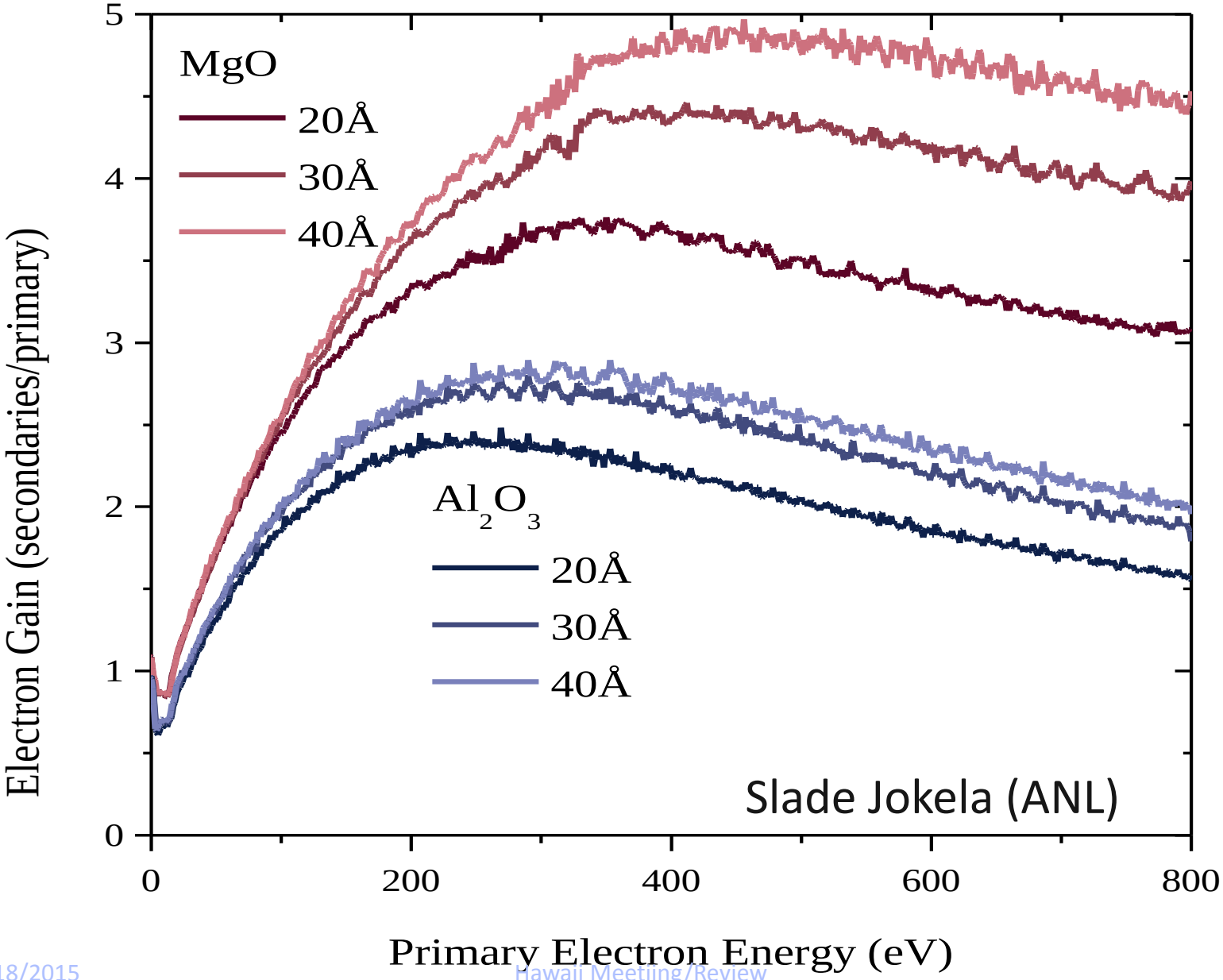
Key R&D Questions have been resolved

- Substrate: glass or AAO (downselect made-AAO patented)
- Secondary-emission layer- measure SEY's from ALD
- ALD resistive layer on micropores
- MCP performance: gain, uniformity, stability, lifetime
- Good QE uniform 20-cm photocathode deposition
- Photocathode lifetime on B33 glass
- Smaller feature (130nm process) analog wave-form ASIC
- Psec level system development (clock, multichannel)
- High bandwidth low channel-count readout system
- Packaging- anode to sidewall seal (fritting)
- Packaging- sidewall to window seal (top seal)

Many of these could have been a showstopper. All of these have been done.

*** There are R&D questions for alternative, possibly better, solutions, but an adequate solution has been demonstrated for each of these individually**

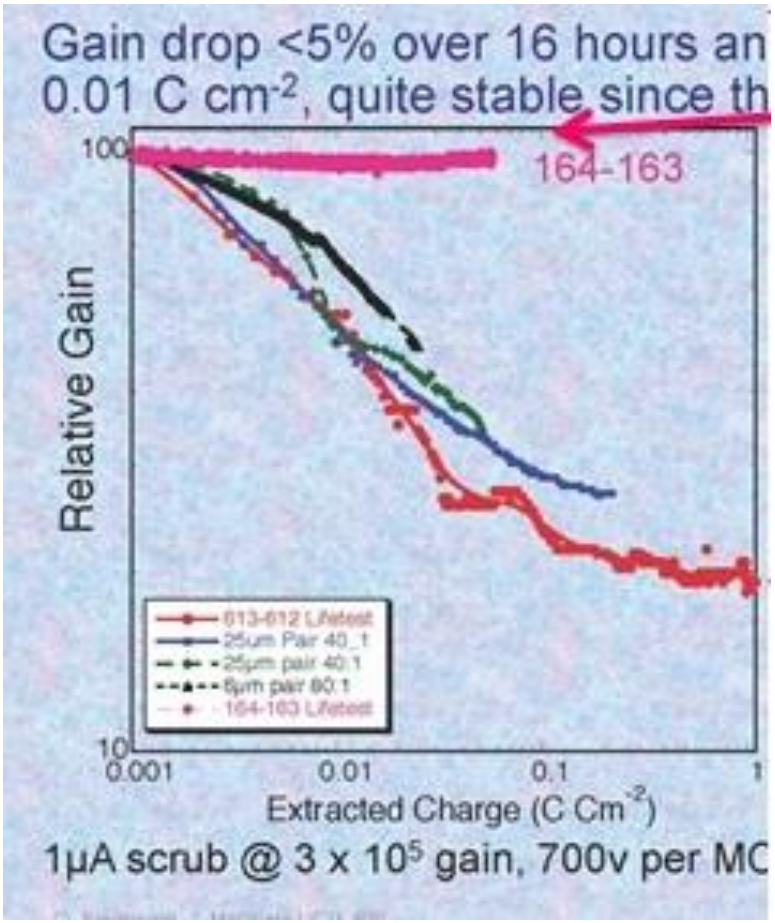
Example of key R&D from the ANL-MSD MCP group



(2011? slide)

Example of key R&D from Ossy's group

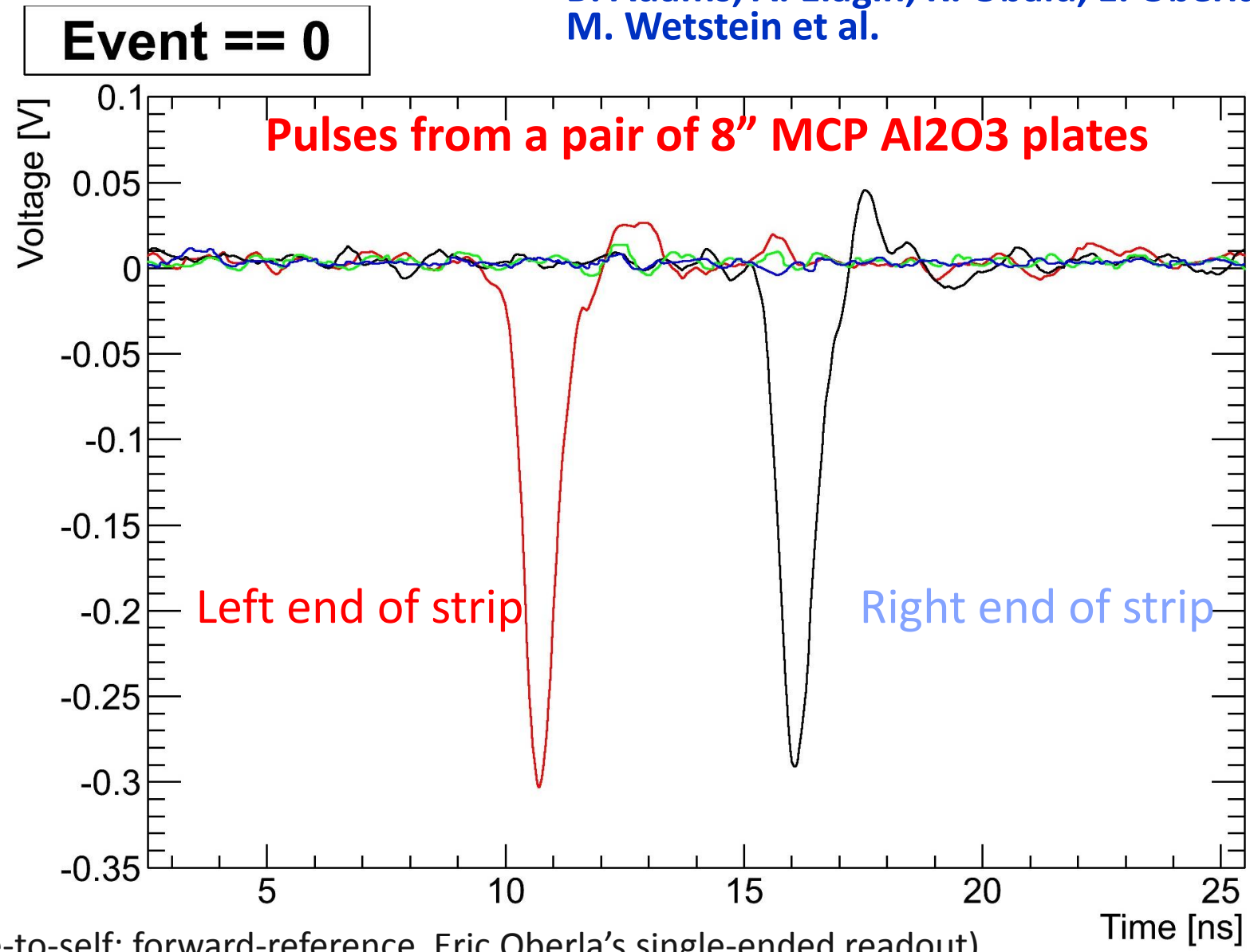
Industry has taken note of the unscrubulous (sic) property of ALD-functionalized plates- has a very large effect on the throughput, and hence the economics, of MCP-based tube production.



Old slide

Example of key R&D from the UC ANL-XSD group

B. Adams, A. Elagin, R. Obaid, E. Oberla, M. Wetstein et al.

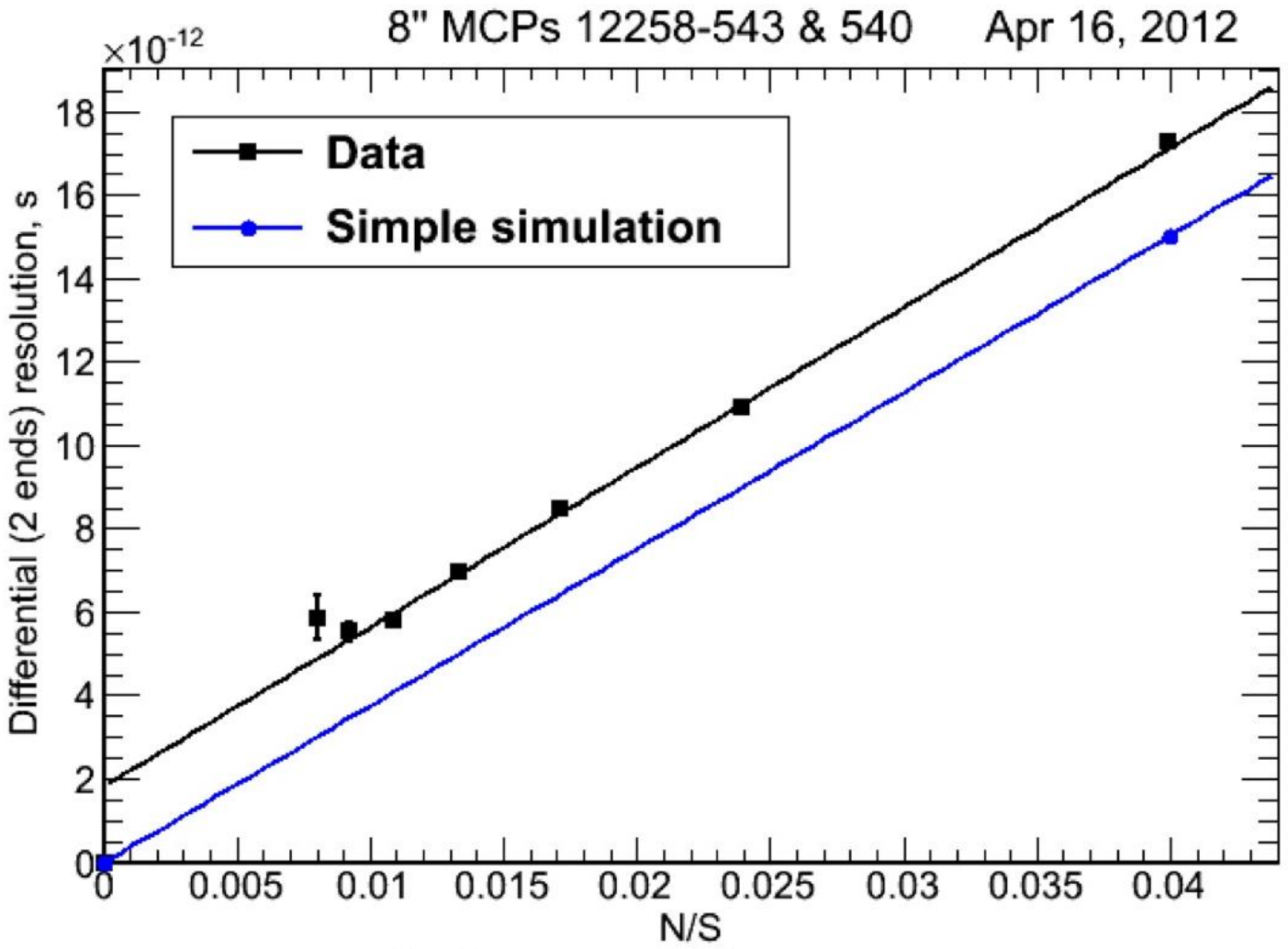


(Note-to-self: forward-reference Eric Oberla’s single-ended readout)

Old slide

Lastly, pushing the boundaries

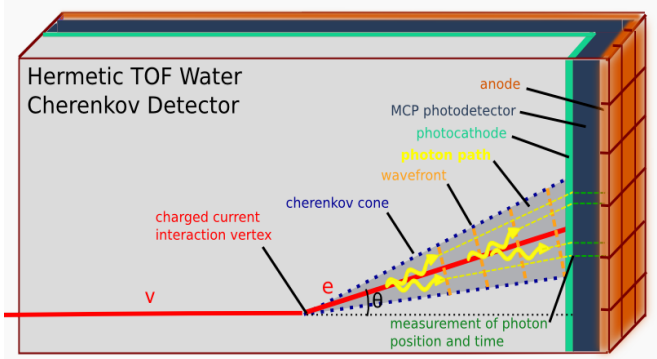
pico-seconds

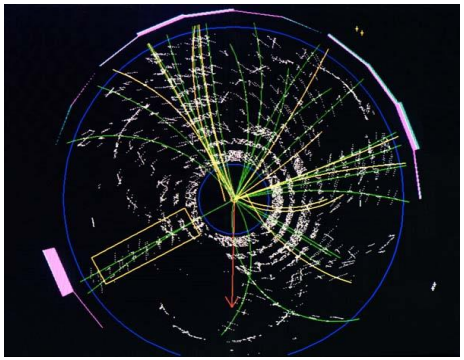


N = RMS of the noise; S = signal amplitude

Old slide (2012?)

DUSEL Detector Motivation vs Collider





Howard Nicholson (DOE) recognized that these detectors could be used in large water-Cherenkov ν detectors

- **DUSEL plan was 150-300 M$ for PMT"s, all non-US**
- **Howard advocated high-risk high-return (see PCAST report);**
- **Ancillary benefits-**
  - **Non-implosive (low volume, can be thick glass)**
  - **Insensitive to Earth's magnetic field**
- **Howard spoke of a 4'x8' panel with a single fiber readout (!).**

- **The LAPPD R&D addressed both large-area and fast time resolution applications – good time resolution is intrinsic.**

(2010 slide)

DUSEL-driven Tech Transfer Proposal

What follows, although now dated, is confidential. I would like to show it as this commercial proposal and its context played a big role in the history and is relevant to the question of manufacturability, but we should not show it if there is concern from any of the participants.

These following slides are from a proposal in 2010 to make 100,000 LAPPD Tiles by a large company experienced in making phototubes.

Slide from Confidential Company-X Proposal

Key Technologies- assessment

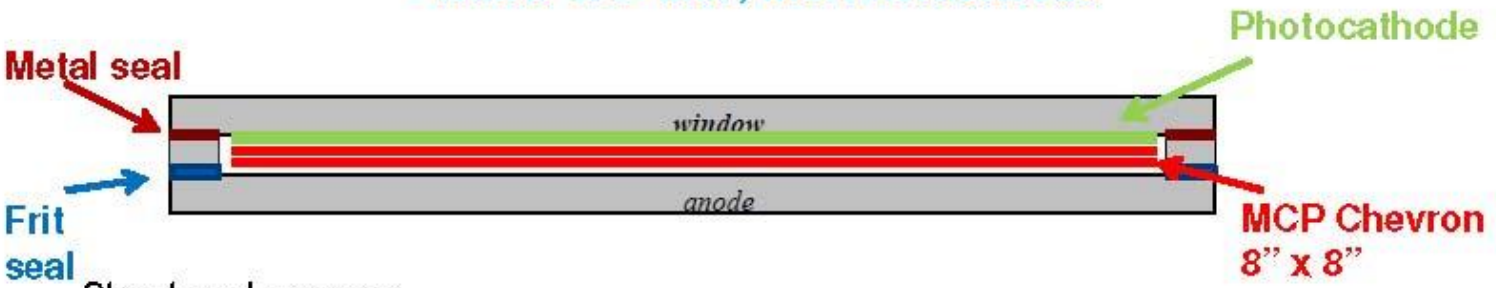
Technologies required	Available at [redacted]
• Glass – glass – metal seals	yes
• Ceramic - metal seals	yes
• Clean room	yes
• Vacuum tube chemistry	yes
• Photo cathode process	yes
• III – V semiconductors	yes
• Vacuum transfer technology	yes
• Electron / UV degassing	yes
• Getter activation	yes
• Indium Seal	yes
• PMT testing	yes
• Micro capillaries	No
• Resistive and emissive coating	No

9 Confidential [redacted] is well-suited as potential partner

Slide from Confidential Proposal

Task 1: Develop 8" x 8" tile with Photocathode and full size MCP

- With 8" x 8" MCP, with Photocathode



Structured program

1. Adapt tile design to suit Transfer technology and process (as needed)
2. Deliver tile with hermetic frit and metal seal (no photocathode, no MCP)
3. Deliver tile with photocathode
4. Deliver fully functional sample with photocathode and MCP
5. Process optimization / life time

- Duration of all 5 steps: 24 months
- Required MCPs and initial parts delivered from Argonne

12 Confidential

Duration: 24 months

Slide from Confidential Proposal

Delivery Schedule: provisional… allowing for ramp-up etc

Deliverable	2011	2012	2013	2014	2015	2016	2017	2018	2019
First tile prototypes		summer							
First functional modules		Fall							
Initial funding: 15k pc order		summer							
Production Units, machine #1, 1000's			3 ramp	4	7	7	7	7	7
Final funding: 85 k pc order			summer						
Production units Machines #2,#3 (1,000's)					2 ramp	14	14	14	14
Cumulative units			3	4	16	30	58	79	100
"Desired" schedule			start		First 10k		Next 40k		Final 51k

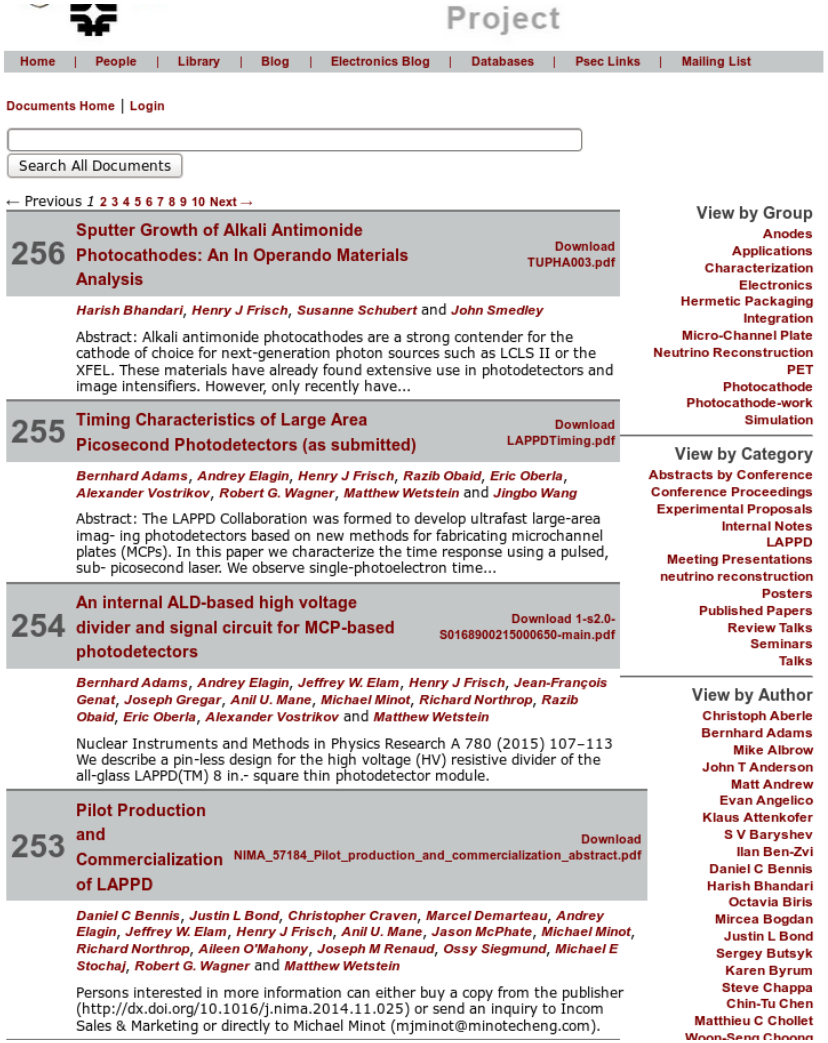
!

20 Confidential

Ready for volume production mid 2013

LAPPD Papers, Patents, and Trademark

Our papers, patents, notes are available at the Document Library on the PSEC web page (psec.uchicago.edu/library)-



Project

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256 Sputter Growth of Alkali Antimonide Photocathodes: An In Operando Materials Analysis — Download TUPHA003.pdf

Harish Bhandari, Henry J Frisch, Susanne Schubert and *John Smedley*

Abstract: Alkali antimonide photocathodes are a strong contender for the cathode of choice for next-generation photon sources such as LCLS II or the XFEL. These materials have already found extensive use in photodetectors and image intensifiers. However, only recently have...

255 Timing Characteristics of Large Area Picosecond Photodetectors (as submitted) — Download LAPPDTiming.pdf

Bernhard Adams, Andrey Elagin, Henry J Frisch, Razib Obaid, Eric Oberla, Alexander Vostrikov, Robert G. Wagner, Matthew Wetstein and *Jingbo Wang*

Abstract: The LAPPD Collaboration was formed to develop ultrafast large-area imag- ing photodetectors based on new methods for fabricating microchannel plates (MCPs). In this paper we characterize the time response using a pulsed, sub- picosecond laser. We observe single-photoelectron time...

254 An internal ALD-based high voltage divider and signal circuit for MCP-based photodetectors — Download 1-s2.0-S0168900215000650-main.pdf

Bernhard Adams, Andrey Elagin, Jeffrey W. Elam, Henry J Frisch, Jean-François Genat, Joseph Gregar, Anil U. Mane, Michael Minot, Richard Northrop, Razib Obaid, Eric Oberla, Alexander Vostrikov and *Matthew Wetstein*

Nuclear Instruments and Methods in Physics Research A 780 (2015) 107–113 We describe a pin-less design for the high voltage (HV) resistive divider of the all-glass LAPPD(TM) 8 in.- square thin photodetector module.

253 Pilot Production and Commercialization of LAPPD — Download NIMA_57184_Pilot_production_and_commercialization_abstract.pdf

Daniel C Bennis, Justin L Bond, Christopher Craven, Marcel Demarteau, Andrey Elagin, Jeffrey W. Elam, Henry J Frisch, Anil U. Mane, Jason McPhate, Michael Minot, Richard Northrop, Aileen O'Mahony, Joseph M Renaud, Ossy Siegmund, Michael E Stochaj, Robert G. Wagner and *Matthew Wetstein*

Persons interested in more information can either buy a copy from the publisher (http://dx.doi.org/10.1016/j.nima.2014.11.025) or send an inquiry to Incom Sales & Marketing or directly to Michael Minot (mjminot@minotecheng.com).

View by Group
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Karen Byrum
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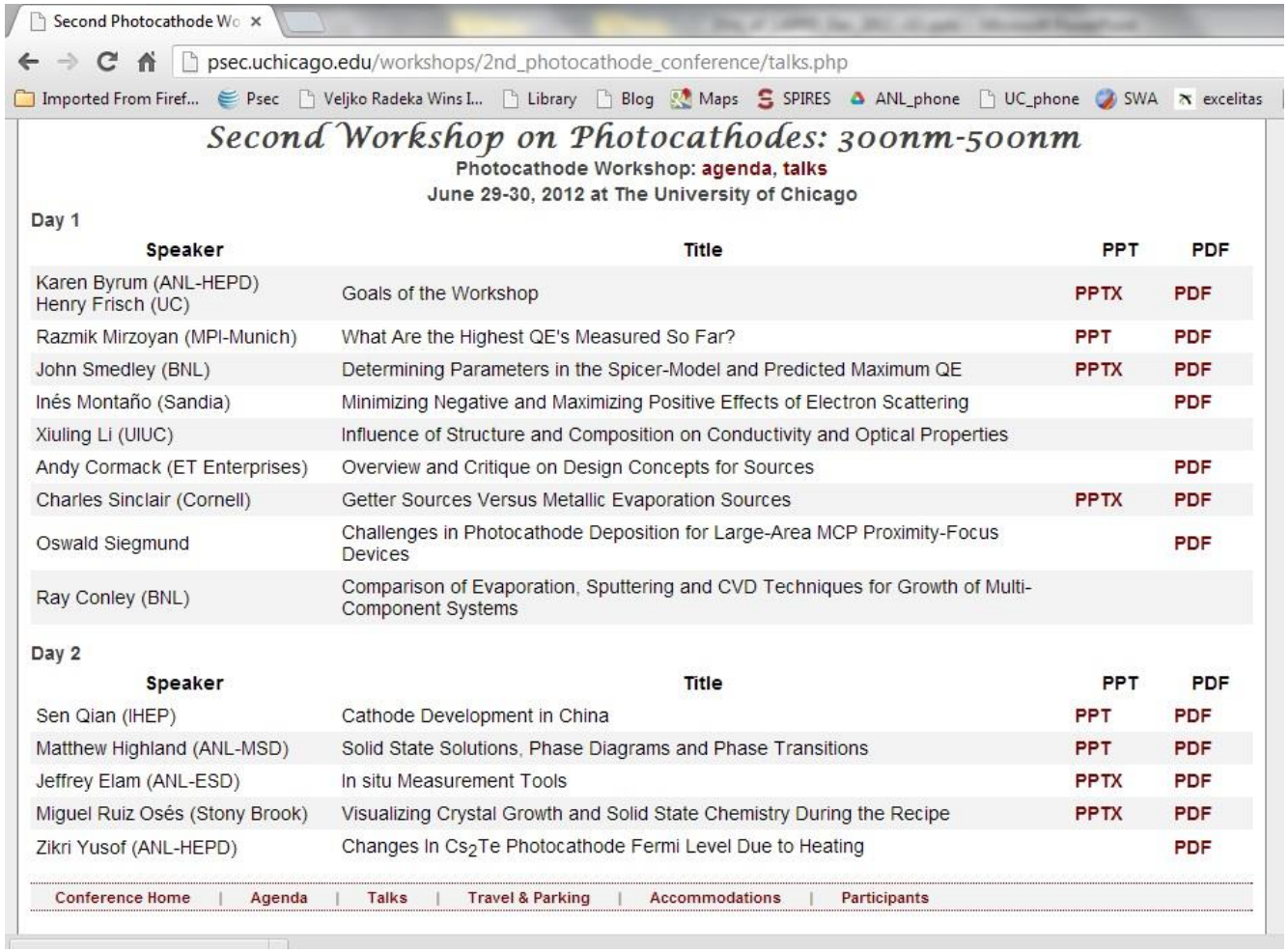
Chin-Tu Chen
Matthieu C Chollet
Woon-Seng Choong

Searchable by category (e.g. Published, author, subject,..)- thanks to Mary Heintz

Other Impacts

We may have had influence in interesting industry in probing the limits of high QE for photocathodes



Second Photocathode Wo ×

psec.uchicago.edu/workshops/2nd_photocathode_conference/talks.php

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Second Workshop on Photocathodes: 300nm-500nm

Photocathode Workshop: agenda, talks

June 29-30, 2012 at The University of Chicago

Day 1

Speaker	Title	PPT	PDF
Karen Byrum (ANL-HEPD) Henry Frisch (UC)	Goals of the Workshop	PPTX	PDF
Razmik Mirzoyan (MPI-Munich)	What Are the Highest QE's Measured So Far?	PPT	PDF
John Smedley (BNL)	Determining Parameters in the Spicer-Model and Predicted Maximum QE	PPTX	PDF
Inés Montaño (Sandia)	Minimizing Negative and Maximizing Positive Effects of Electron Scattering		PDF
Xiuling Li (UIUC)	Influence of Structure and Composition on Conductivity and Optical Properties		
Andy Cormack (ET Enterprises)	Overview and Critique on Design Concepts for Sources		PDF
Charles Sinclair (Cornell)	Getter Sources Versus Metallic Evaporation Sources	PPTX	PDF
Oswald Siegmund	Challenges in Photocathode Deposition for Large-Area MCP Proximity-Focus Devices		PDF
Ray Conley (BNL)	Comparison of Evaporation, Sputtering and CVD Techniques for Growth of Multi-Component Systems		

Day 2

Speaker	Title	PPT	PDF
Sen Qian (IHEP)	Cathode Development in China	PPT	PDF
Matthew Highland (ANL-MSD)	Solid State Solutions, Phase Diagrams and Phase Transitions	PPT	PDF
Jeffrey Elam (ANL-ESD)	In situ Measurement Tools	PPTX	PDF
Miguel Ruiz Osés (Stony Brook)	Visualizing Crystal Growth and Solid State Chemistry During the Recipe	PPTX	PDF
Zikri Yusof (ANL-HEPD)	Changes In Cs_2Te Photocathode Fermi Level Due to Heating		PDF

Conference Home | Agenda | Talks | Travel & Parking | Accommodations | Participants

Lots of Industrial folks at the workshop- recent big advances by ADIT, Hamamatsu and Photonis; still don't know the limit. (R&D component of our program.)

Other Impacts

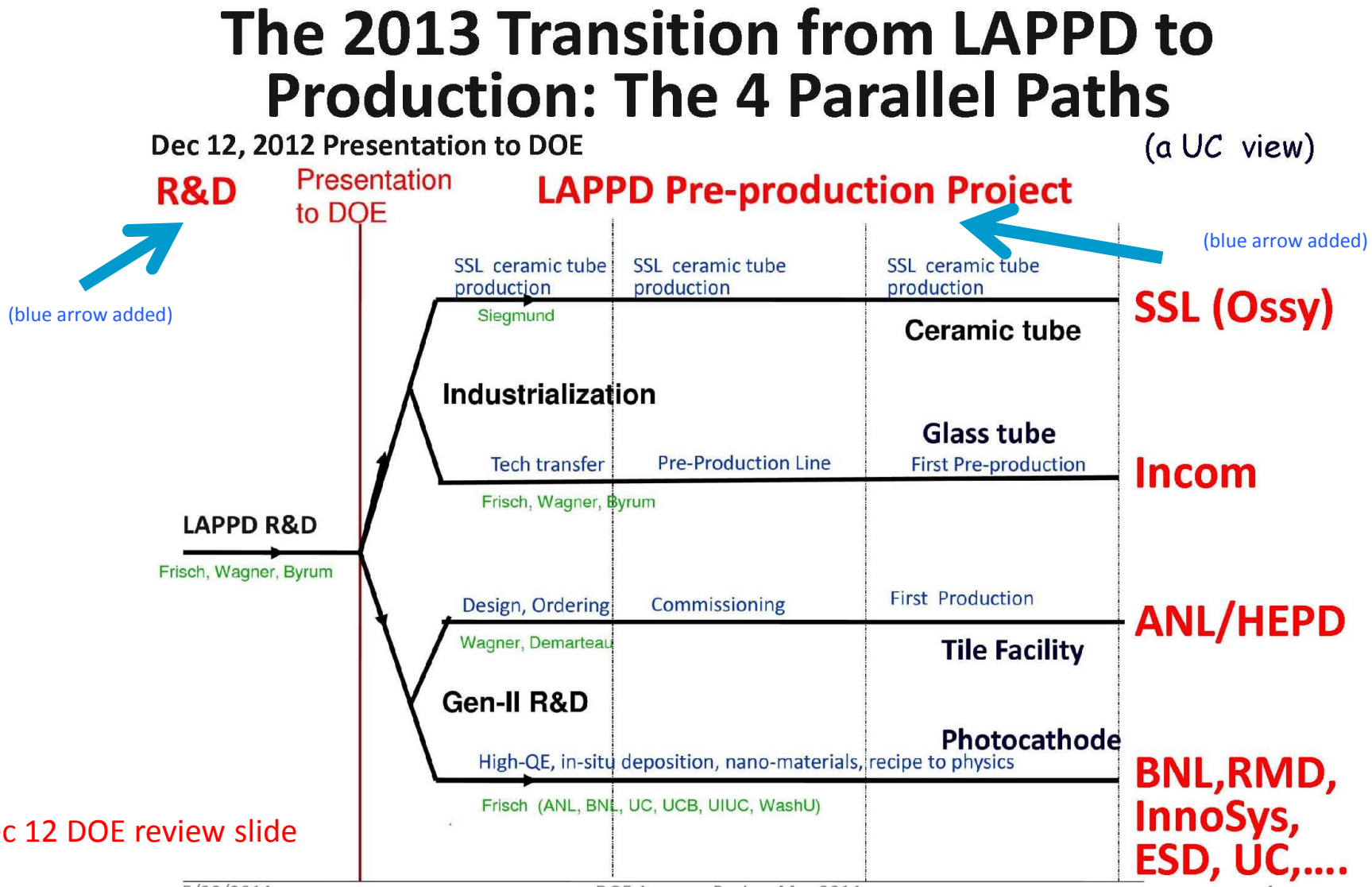
Giving young talented people (future Ypsilantis's, Charpaks, Cronins, Nygrens, ..) the opportunity to work on instrumentation with a big impact (attractive to academic departments, e.g. UC).

- **Tim Credo, IMSA HS student, came in 2nd in the Intel Science talent search (did our first anodes- gave a talk at IEEE in Rome in 2004**
- **Matt Wetstein- Grainger Postdoctoral Fellowship in UC Physics Dept.**
- **Eric Oberla- Grainger Graduate Student Fellowship in UC Physics Dept.**
- **Mayly Sanchez- Early Career Award (LAPPD and nu's)**
- **Plus several superb students who have been mentored at ANL and elsewhere: Mark Kupfer (UIC), Razib Obaid (IIT/UC),…**

Old Slide

Beyond LAPPD- Transition to PreProduction

- **The LAPPD Collaboration ended with the Dec 12 DOE Review at ANL- the following plan was shown:**



Dec 12 DOE review slide

Making a Sealed Functional Tile

The one LAPPD milestone that wasn't met was the integration of the R&D into a sealed functional tile.

In hindsight, unlike the integration of electronics into a system or the development of the ALD-coated substrates, this milestone was different in nature from the focused R&D that we successfully did- it was a mistake (buck stops with me) to treat it as R&D.

The 3 ½ years of R&D was not atypical; the next step in developing a new technology is typically ~5 years. We have found no show-stoppers, but even given that all the steps have been proven individually, it is not a simply-connected linear task– it takes time and immense expertise.

My Own Questions For the Committee and Collaborators

(Asked at the risk of slings and arrows, but also as one of the initiators and former Spokesperson of LAPPD- lots of skin invested. I have my own answers, but it could help a lot to know the opinions of experts from the larger community.).

1. **Is the technology viable? (i.e. are there showstoppers?)**

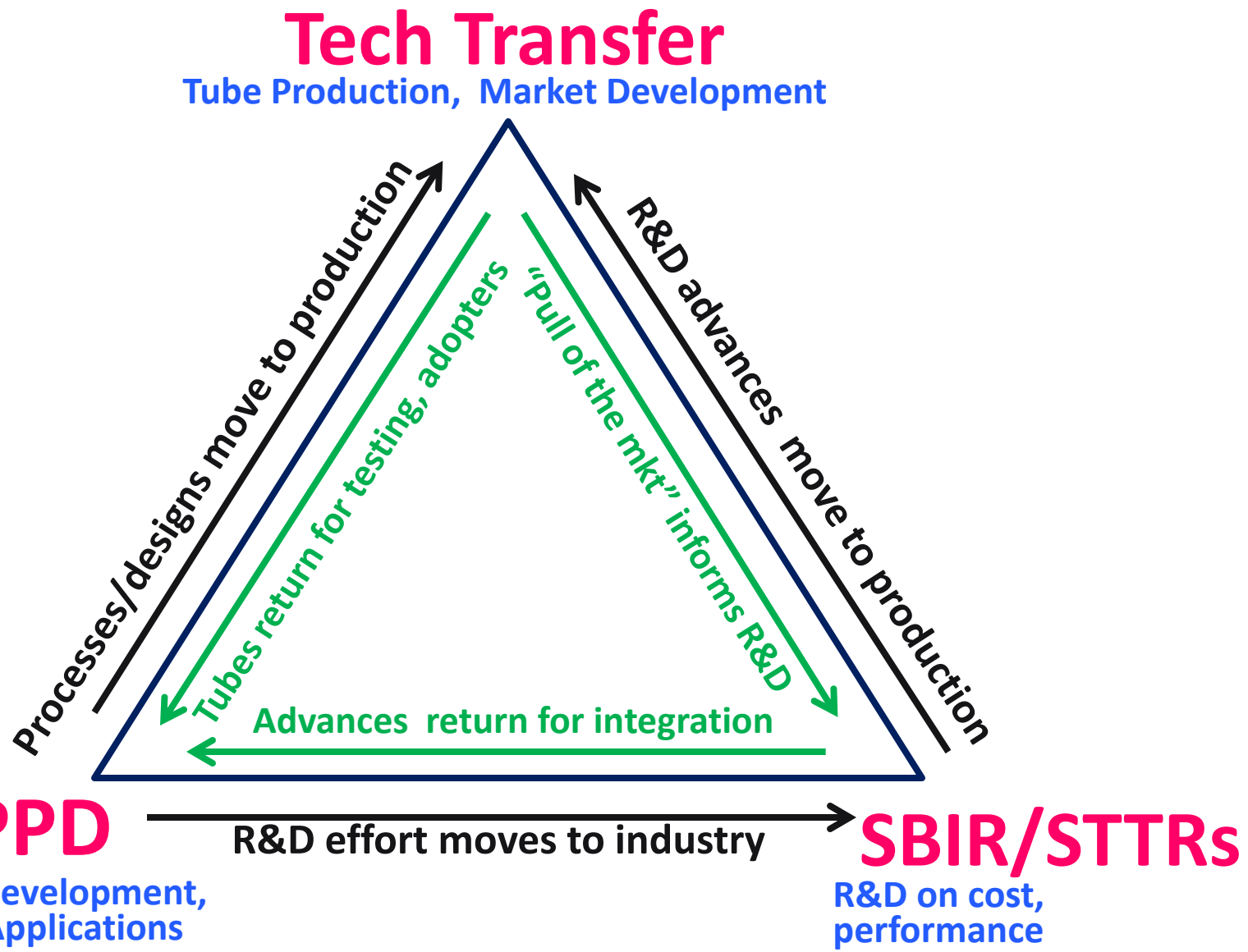
2. **Would the technology be transformative in security, and scientific use, in particular High Energy and Nuclear Physics?**

3. **If yes, are we comfortable to have it developed by non-US companies (other nations have shown great interest in our R&D), or should we make a sustained effort in the US?**

The End

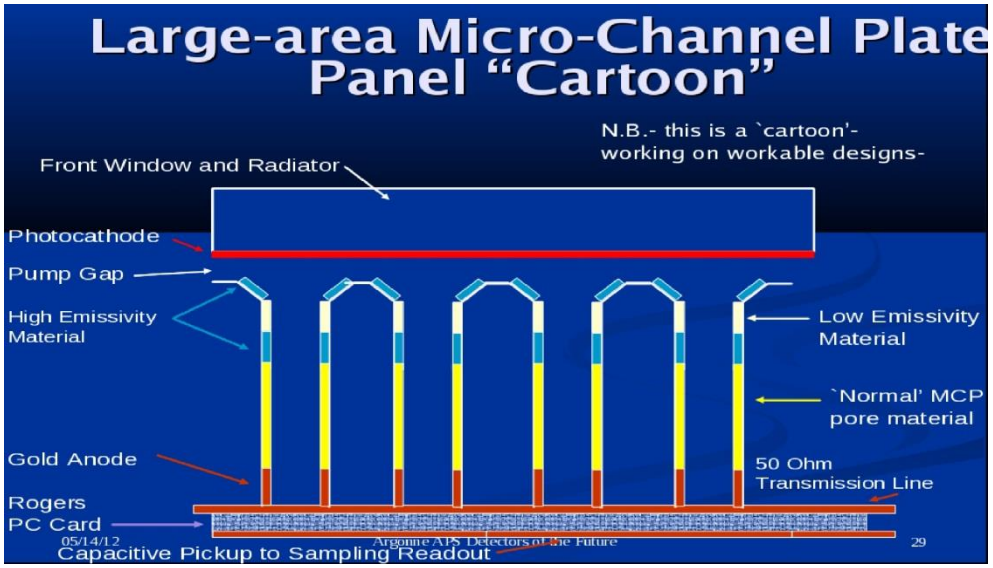
BACKUP SLIDES

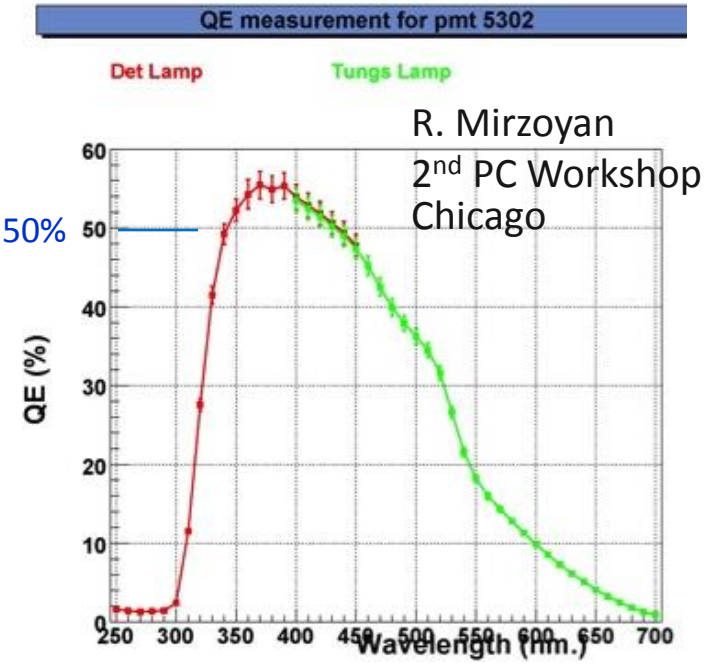
The Transition from 3 Years of R&D to Applications: Roles of SBIR/STTR and TTO



A Vision of the Upside of the Technology

Each of the 4 Areas of LAPPD has an unknown limit on development





Photocathodes: VHQE

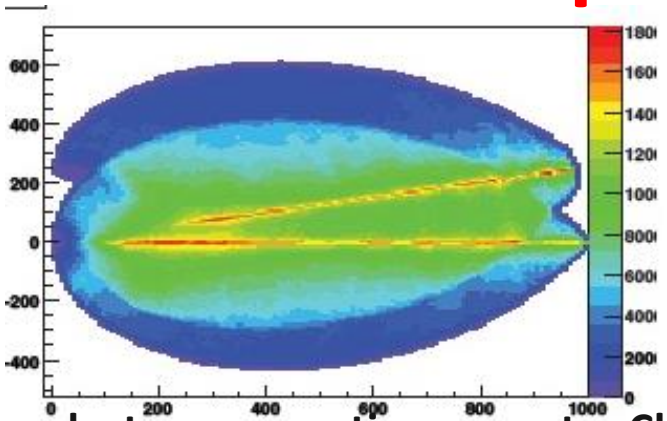
Ultra-low TTS MCP development

U	Δu	f_s	f_{3db}	Δt
100 mV	1 mV	2 GSPS	300 MHz	~10 ps
1 V	1 mV	2 GSPS	300 MHz	1 ps
100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
1V	1 mV	10 GSPS	3 GHz	0.1 ps

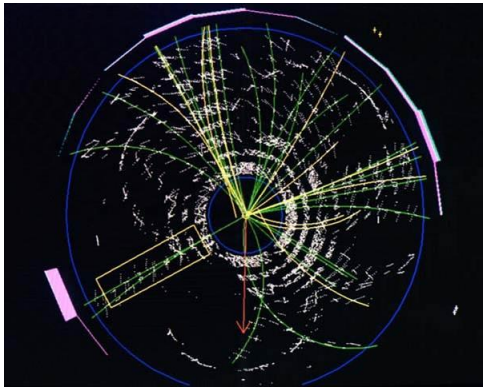
Electronics: Deep Sub-psec Time Resolution

Packaging: sealed flat-panel

The Relationship of SBIR/STTR/TTO to Needs



Pizero-electron separation on water Ch. cters



Collider TOF for vertex sep., family flow

Higher performance
Or
Lower Cost
Are
The main benefits

("F,B,C-
pick any two")

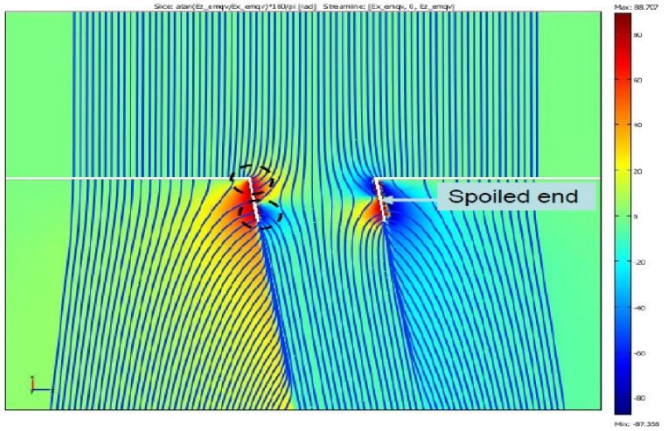
LAPPD Markets: Need. Applications. Benefit. and Competition

Application	Market Need	Approach	Benefit	Competition
Non-cryogenic Tracking Neutrino Detectors	HEP-Fermilab	Very-large-area, bialkali-cathode	Bkgd rejection, Cost, Readiness	Liquid Argon
LE Neutron Detection	Neutron Diffraction	B or Gd Glass, no cathode	Time and Position resolution, pulse shape γ/n differentiation, Large area	He3, B tubes
LE Neutron Detection	Transportation Security	B or Gd Glass, no cathode	Large area pulse shape γ/n differentiation, Large area	He3, B tubes
LE Anti-Neutrino Detection	Reactor Monitoring	Large-area, bialkali-cathode	Efficiency, Cost	PMT's, SiPMs
HE Collider Vertex Separation	CERN	Psec TOF	Resolution, Radiation-Hard	Silicon Vertex
HE Collider Particle ID	CERN, Future Lepton Collider	Psec TOF	Resolution, Reach in P_T	None
π^0/η Reconstruction and ID	Rare K Decays (JPARC), Fermilab	Psec TOF	Combinatoric Bkgd Rejection	Conventional TOF
Strange Quark ID	RHIC (BNL), ALICE (LHC) Collider	Psec TOF	Resolution, Reach in P_T	dE/dx
Positron-Emission Tomography	Clinical Medical Imaging	TOF, Large Area	Lower Dose Rate, Faster throughput	SiPM

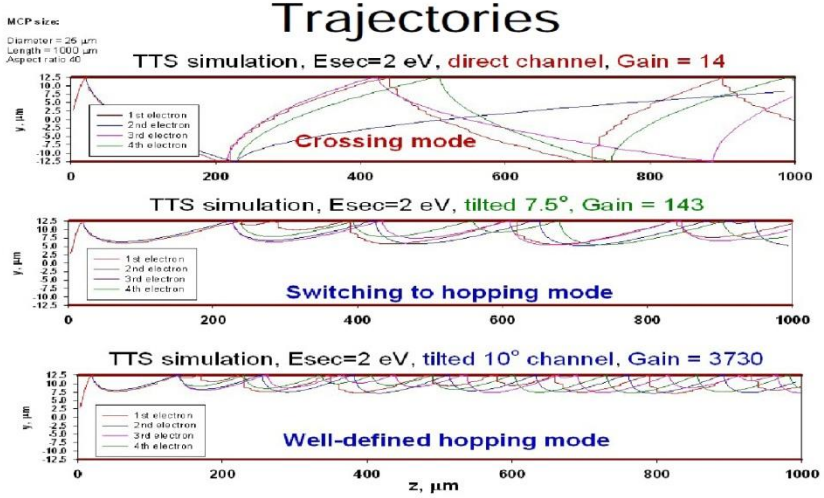
Simulation (crosses all groups)

Valentin Ivanov, Zeke Insepov, Zeke Yusof, Sergey Antipov

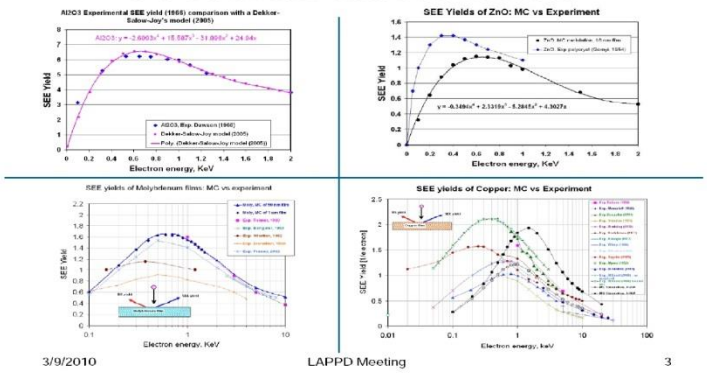
Spoiled end. Color: field angle

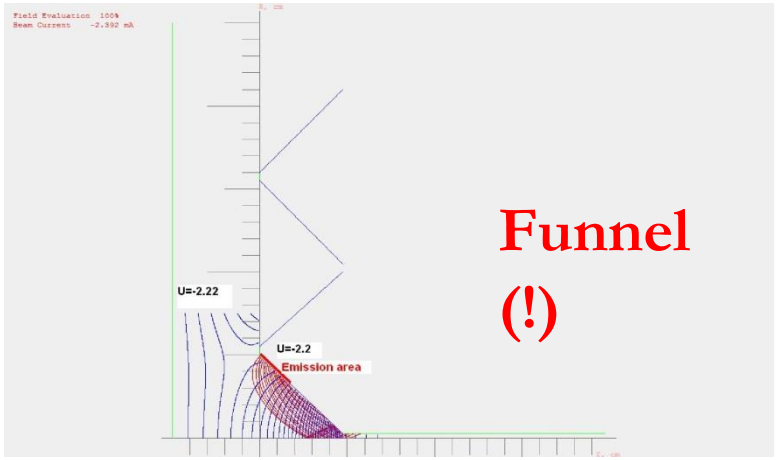


Trajectories



Previous calculations





Status of ARRA Milestones

June 3, 2010

LAPPD Year 2 ARRA Funding Milestones

Milestones for the ARRA funding from July 1, 2010 to June 30, 2011

1. Demonstration of gain of 10^6 and aging performance comparable to or better than that of commercial plates with a pair of capillary MCP plates functionalized by ALD; **Done**
2. Development of an MCP test facility capable of handling 8" plates in tiles; **Done**
3. Functionalization of an 8" × 8" glass capillary substrate with ALD; **Done**
4. Observation of gain from an ALD-functionalized 8" × 8" MCP plate; **Done**
5. Design and costing of a photocathode characterization facility; **Done**
6. Design and costing of an 8" glass tile assembly facility. **Done**

One milestone remains from Year 1: an 8" top seal (SSL hot seal, and ANL top and cold seals in progress)

Work Planned but Slowed/Stopped

1. Substrate development at Incom- large L/D for 1 vs 2 MCP's for large-area apps; 100% Open Area Ratio
2. Providing more effort for ALD development
3. Glass Top Seal Development at ANL and UC (engineering effort and equipment)
4. Glass Tile package optimization (parts and labor)
5. Photocathode effort at ANL (effort)
6. Electronics: cut ASIC orders, improved versions
7. Building ANL detector group (replacing postdocs, material science expertise, 1 senior hire for Single Tile Facility, photocathodes)